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APPLICATION OF OPTIMIZATION METHODS ON ABRASIVE JET MACHINING OF CERAMICS

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ABSTRACT

In this paper, Taguchi method is applied to find optimum process parameter for Abrasive jet machining. Abrasive jet machining is a modern machining process in which the Metal Removal takes place due to the impact of High Pressure, High Velocity of Air and Abrasive particle (Al2O3, Sic etc.) on a work piece. Experimental investigation were conducted to assess the influence of Abrasive jet machining process parameters on MRR and Kerf of fibre glass. The approach was based on Taguchi's method and analysis of variance to optimize the AJM process parameters for effective machining and to predict the optimal Values for each AJM parameter such as pressure, standoff distance, Abrasive flow rate and Nozzle diameter. For each combination of orthogonal array we have conducted four experiments and with the help of ANOVA it is found that the process parameters have a significant influence on metal removal rate and Kerf. The Experimental analysis of the Taguchi method identifies that, in general the Pressure significantly affects the MRR while, Stand of distance affects the Kerf. Experiments are carried out using (L16) orthogonal array by varying pressure, standoff distance, Abrasive flow rate and Nozzle diameter respectively.

KEYWORDS: MRR, Kerf, Taguchi, Analysis of Variance, Orthogonal Array

INTRODUCTION

Abrasive jet machining process consists of directing a stream of fine Abrasive grains, mixed with compressed air or some other gas at high pressure through a nozzle on to the surface of the work piece to be machined. These particles impinge on the work surface at high speed and the erosion caused by their impact enables the removal of metal. The Metal removal depends on the Abrasive flow rate and grain size of abrasive particles. This process can be established easily because of its low capital investment. In Abrasive jet machining abrasive particles are made to strike on work material at high velocity. The abrasive particles are carried by carrier gas. The high velocity stream of abrasives is generated by converting pressure of gas to its motion energy and hence high velocity jet. Nozzles directs abrasive jet in a controlled manner on to work material. The Metal removal takes place by the high velocity abrasive particles, which removes the material by micro-machining action as well as brittle fracture of the work material.

This is a process of removal of material by impact erosion through the action of concentrated high velocity stream of grit abrasives entrained in high velocity gas stream. AJM is different from shot or sand blasting, as in AJM, finer abrasive grits with different grit sizes are used and process parameters can be more effectively controlled and provides better control over product quality.

Air is filtered and compressed through the filter and passes through compressor. For regulating the pressure a pressure gauge and a Pressure regulator are used and also to maintain uniformity in the flow rate of the compressed air. The air which is compressed is then passed into the mixing chamber where the abrasive particles are mixed with air. A vibrator is used to control and regulate the feed flow of the abrasive powder. The pressure of this mixture is regulated and sent to nozzle.

Due to low nozzle diameters the velocity of the air and abrasive increases at the expense of its pressure. This jet of abrasives is used to remove extra material from the work surface. The material removal rate can be improved by increasing the abrasive flow rate provided the mixing ratio can be kept constant. The mixing ratio is unchanged only by gradual increase of both gas and abrasive flow rate [5].

The abrasive flow rate can be increased by increasing the flow rate of the carrier gas. This is only possible by increasing the internal gas pressure as shown in the figure. As the internal gas pressure increases abrasive mass flow rate increase and thus MRR increases. The material removal rate will increase with the increase in gas pressure. Kinetic energy of the abrasive particles is responsible for the removal of material by erosion process. The abrasive must impinge on the work surface with minimum velocity for machining glass by SIC particle is found to be around 150m/s.

Stand-off distance is defined as the distance between the nozzle face and the surface of the work piece. SOD have been found to have considerable effect on the work material and accuracy [7]. A large SOD results in flaring of jet which leads to poor accuracy.

CERAMICS comes from the Greece word keramicos, which means burnt stuff the ingredients for manufacturing are clays, sand and felspar. Ceramics are usually made by heating natural clays at a high temperature. Typically, clays for ceramics are grouped into two general types: red clay, which contains primarily silicon dioxide and iron oxide; and kaolin clay, which contains mostly aluminium oxide and almost no iron oxide. Because red clay contains more iron, it often has a rusty brown shade somewhere between light tan and dark brown, while pure kaolin clay is white.

Ceramic products are usually divided into four sectors. Structural, including bricks, pipes, floor and roof tiles, Refractories, such as kiln linings, gas fire radian's, steel and glass making crucibles, White wares, including tableware, cookware, wall tiles, pottery products and sanitary ware, Technical, is also known as engineering, advanced, special, and in Japan, fine ceramics. Such items include tiles used in the Space, gas burner nozzles, ballistic protection, nuclear fuel uranium oxide pellets, biomedical implants, coatings of jet engine turbine blades, ceramic disk brake, missile nose cones, bearing (mechanical), etc. Frequently, the raw materials do not include clays. In the Present Experimentation the ceramic tiles are used.

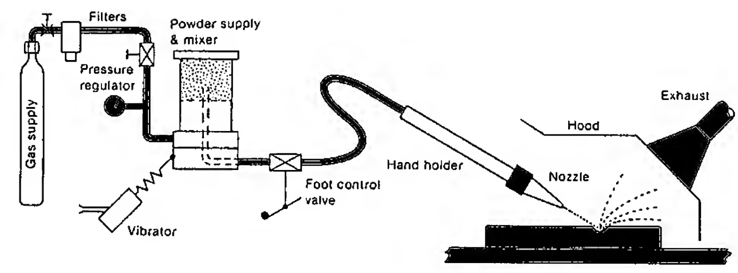

Figure 1: Diagram of Abrasive Jet Machining

METHODOLOGY

Design of experiments (DOE) is a systematic approach which gives solution to the engineering problem- that applies techniques and principles at the data collection stage so as to ensure the generation of valid, defensible, and supportable engineering conclusions. In addition, all of this is carried out under the constraint of a minimal expenditure of engineering runs, time, and money.

The Taguchi method [1,2,3, & 4]is a robust design involves reducing the variation in a process of experiments. The overall objective of the method is to produce high quality product at low cost to the manufacturer. Dr. Genichi Taguchi of Japan was developed this method. This Method proposes using of orthogonal arrays to organize the parameters affecting the process and the levels at which they should be varied; it allows for the collection of the necessary data to determine which factors most affect product quality with a minimum amount of experimentation, thus saving resources and time.

Analysis of variance (ANOVA) is a method that investigates and models the relationship between the variables called a response and independent variables and the variables may be one or more. However, analysis of variance vary from regression in two ways: the independent variables are qualitative, and no assumption is made about the nature of the relationship (that is, the model does not include coefficients for variables). In effect, analysis of variance extends the two-sample t-test for testing the equality of two population means to a more general null hypothesis of comparing the equality of more than two means, versus them not all being equal. Several of MINITAB's ANOVA procedures, however, allow models with both qualitative and quantitative variables.

The F-test of NOVA (standard analysis) is used to analyze the experimental data as mentioned bellow:

Notation

Following Notation are used for calculation of ANOVA method

C.F. = Correction factor

T = Total of all result

n = Total no. of experiments

ST = Total sum of squares to total variation.

Xi = Value of results of each experiments (i = 1 to 27)

SY = Sum of the squares of due to parameter Y (Y = P, S, A, T)

NY1, NY2, NY3 = Repeating number of each level (1, 2, 3) of parameter Y

XY1, XY2, XY3 = Values of result of each level (1, 2, 3) of parameter Y

FY = Degree of freedom (D.O.F.) of parameter of Y

fT = Total degree of freedom (D.O.F.)

fe = Degree of freedom (D.O.F.) of error terms

VY = Variance of parameter Y

Se = Sum of square of error terms

Ve = Variance of error terms

FY = F-ratio of parameter of Y

SY’ = Pure sum of square

CY = Percentage of contribution of parameter Y

Ce = Percentage of contribution of error terms

CF = T2/n

ST = ∑i=1 to 27 Xi2 – CF

SY = (XY12/NY1 + XY22/NY2 + XY32/NY3) – CF

fY = (number of levels of parameter Y) – 1

fT = (total number of results)-1

fe = fT - ∑fY

VY = SY/fY

Se = ST - ∑SY

Ve = Se/fe

FY = VY/Ve

SY’ = SY – (Ve*fz)

CY = SY’/ST * 100%

Ce = (1- ∑PY)*100%

EXPERIMENTATION & RESULTS

The Equipment used for the Experimentation was Abrasive Jet Machine which was designed and Fabricated at the workshops of St Martin’S Engineering College, Secunderabad. The Experiments at various levels were conducted on the test rig. Nozzles of different sizes are made using tungsten carbide (1mm, 2mm, 3mm, 4mm). A reciprocating type compressor has been used for the supply of air, a dehumidifier was connected to the compressor to control the moisture in air and hence helps for free flow of the mixture.

Figure 2: The Abrasive Machining Setup Established at SMEC

In this experimentation L16 orthogonal array was used. This array consists of four Process parameters called control parameters and four levels, as shown in table 1. In theTAGUCHI method, all the observed values are calculated based on ‘the higher the better’ and ‘the smaller the better’. Thus in this study, the MRR values was set as maximum, and KERF was set to minimum respectively [6]. Next experimental trial was conducted with four simple levels at each set value. The optimisation of the observed values was determined by comparing the standard analysis by analysis of variance (ANOVA) which was based on the Taguchi method.

Table 1: Control Parameters and Levels for Orthogonal Array

PARAMETERS	LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4
PRESSURE (kg/cm^2)	5	6	7	8
ABRASIVE FLOW RATE(g/sec)	3.5	4	4.5	5
SOD (mm)	10	15	20	25
NOZZLE DIAMETER (mm)	1	2	3	4

Table 2: Experimental Design Matrix and Results

S NO	Pressure (kg/cm^2)	AFR (g/sec)	SOD (mm)	ND (mm)	MRR (gm/sec)	PSNRA1	KERF	PSNRA1_2
1	5	3.5	10	1	0.0312	-29.4962	2.8	-8.07122
2	5	4	15	2	0.0469	-26.0757	3.1	-9.48077
3	5	4.5	20	3	0.0671	-23.8237	4.3	-13.5606
4	5	5	25	4	0.0973	-21.0012	5	-14.3066
5	6	3.5	15	3	0.0758	-23.17	2.7	-8.95447
6	6	4	10	4	0.0713	-23.2964	3.5	-11.7726
7	6	4.5	25	1	0.0445	-26.5319	4.3	-12.3229
8	6	5	20	2	0.0537	-24.7798	5.8	-14.3966
9	7	3.5	20	4	0.0816	-21.2653	3.6	-10.7796
10	7	4	25	3	0.0871	-20.5789	4.1	-11.3837
11	7	4.5	10	2	0.0615	-24.9859	5.3	-14.8127
12	7	5	15	1	0.0528	-25.9055	4.4	-13.7603
13	8	3.5	25	2	0.0739	-22.9853	2.5	-8.85
14	8	4	20	1	0.0496	-26.8538	3	-9.86962
15	8	4.5	15	4	0.0815	-21.1561	5.6	-14.0918
16	8	5	10	3	0.0738	-22.138	6.1	-15.3601

Table 3: Response Table for S/N Ratios (Larger is Better)

Level	Pressure	AFR	SOD	Nozzle Diameter
1	-25.1	-24.23	-24.98	-27.2
2	-24.44	-24.2	-24.08	-24.71
3	-23.18	-24.12	-24.18	-22.43
4	-23.28	-23.46	-22.77	-21.68
Delta	1.92	0.77	2.2	5.52
Rank	3	4	2	1

Table 4: Response Table for S/ N Ratios (Smaller is Better)

Level	Pressure	SOD	AFR	Nozzle Diameter
1	-11.355	-9.164	-12.504	-11.006
2	-11.862	-10.627	-11.572	-11.885
3	-12.684	-13.697	-12.152	-12.315
4	-12.043	-14.456	-11.716	-12.738
Delta	1.329	5.292	0.932	1.732
Rank	3	1	4	2

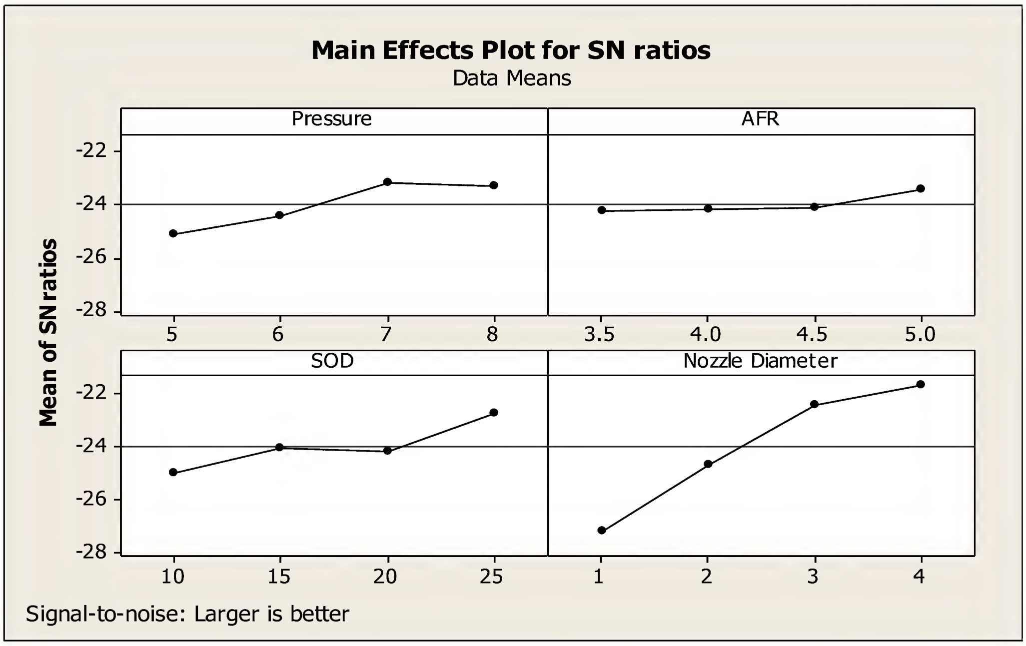

Figure 3: Graphs Indicates the Effect of Pressure, AFR, Sod, Nozzle Diameter on MRR

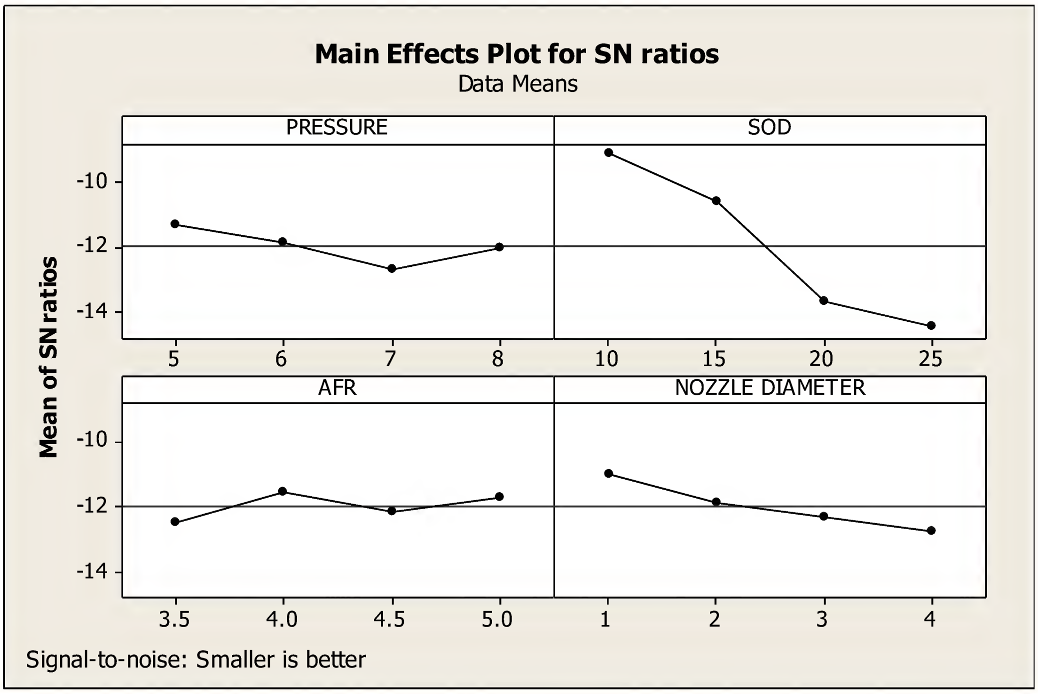

Figure 4: Graphs Indicates the Effect of Pressure, AFR, Sod, Nozzle Diameter on KERF

ANOVA F-Test Results

General Linear Model: Mrr (Gm/Sec) Versus Pressure, Afr, Sod, Nozzle Diameter

Table 5: Factors with Levels and Values for F-Test (MRR)

Factor	Type	Levels	Values			
Pressure	fixed	4	5,	6,	7,	8
AFR	fixed	4	3.5,	4.0,	4.5,	5
SOD	fixed	4	10,	15,	20,	25
ND	fixed	4	1,	2,	3	4

Table 6: Analysis of Variance for MRR (gm/sec), Using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Pressure	3	0.0003454	0.0003454	0.0001151	1.72	0.334
AFR	3	0.0000870	0.0000870	0.0000290	0.43	0.745
SOD	3	0.0005937	0.0005937	0.0001979	2.95	0.199
ND	3	0.0035800	0.0035800	0.0011933	17.79	0.021
Error	3	0.0002013	0.0002013	0.0000671		
Total	15	0.0048074				

S = 0.00819095 R-Sq = 95.81% R-Sq(adj) = 79.07%

General Linear Model: KERF versus PRESSURE, SOD, AFR, NOZZLE DIAMETER

Table 7: Factors with Levels and Values for F-Test (Kerf)

Factor	Type	Levels	Values			
Pressure	fixed	4	5,	6,	7,	8
AFR	fixed	4	3.5,	4.0,	4.5,	5
SOD	fixed	4	10,	15,	20,	25
ND	fixed	4	1,	2,	3	4

Table 8: Analysis of Variance for KERF, Using Adjusted SS for Tests

Source	DF	SeqSS	Adj SS	AdjMS	F	P
PRESSURE	3	0.7569	0.7569	0.2523	0.43	0.748
SOD	3	15.9719	15.9719	5.3240	9.01	0.052
AFR	3	0.5819	0.5819	0.1940	0.808	0.555
ND	3	1.4919	1.4919	0.33	0.4973	0.84
Error	3	1.7719	1.7719	0.5906		
Total	15	20.5744				

S = 0.768521 R-Sq = 91.39% R-Sq(adj) = 56.94%

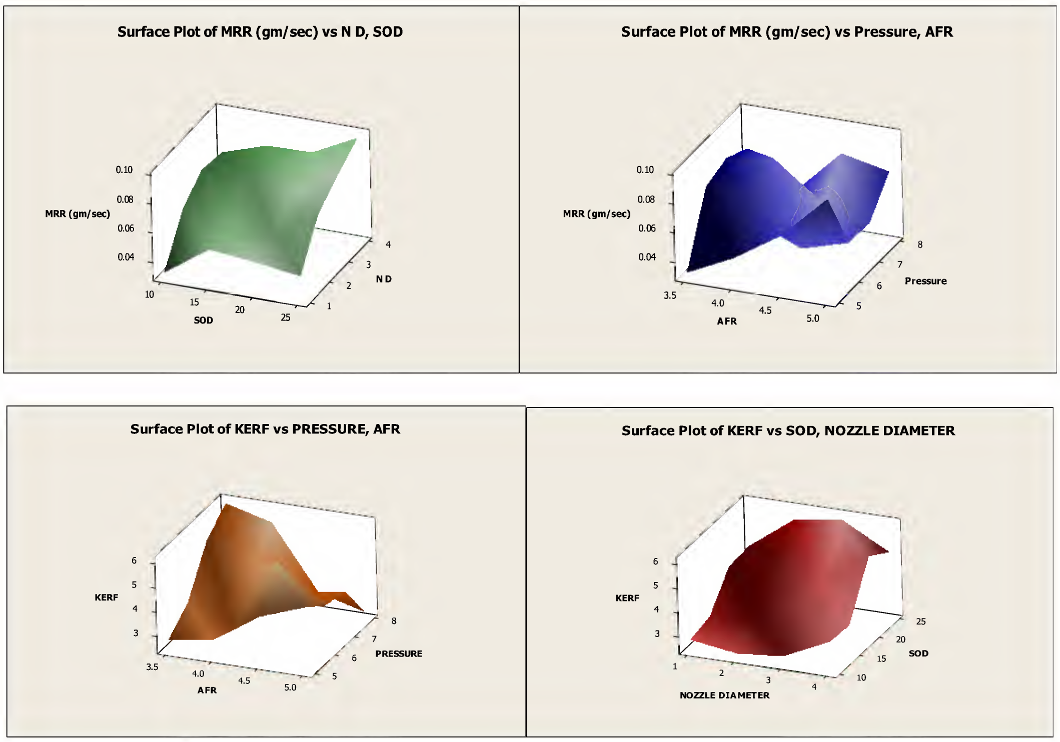

Figure 5: Surface Plots of Process Parameters vs MRR and KERF

These 3D Surface plots indicates the variation of Pressure, AFR, SOD, Nozzle Diameter on Metal Removal Rate and Kerf (width of cut). The Graphs obtained by TAGUCHI METHOD are coinciding with the values of F-Test in Analysis of Variance (ANOVA).

The Experimental Results gives much awareness about the Method used for optimizing the parameters and the optimal values that can be considered for better machining, the same results are validated by ANOVA. The results of Taguchi are similar to the F-Test values of Analysis of Variance.

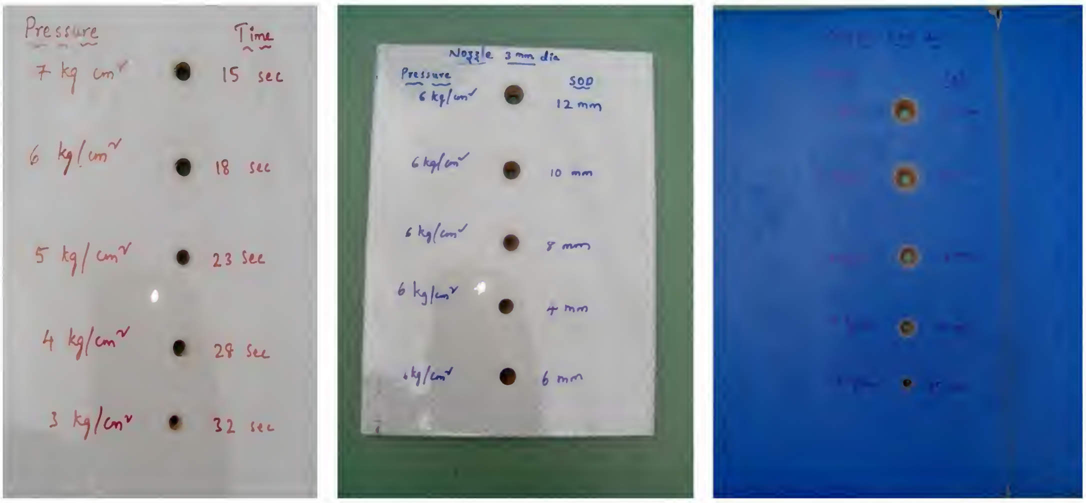

Figure 6: Ceramic Tiles Drilled at Different Pressure, SOD, and AFR with the Variance of Different Times

CONCLUSIONS

In the present study experimental investigations have been carried for the width of cut and MRR in abrasive jet Machining of Ceramic tile. The effects of different operational parameters such as pressure, abrasive flow rate, nozzle diameter and standoff distance on MRR and width of cut have been studied. As a result of this study, it is observed that these operational parameters have direct effect on both MRR and Kerf. The Application of optimization methods on the Abrasive jet drilling was successfully performed. First the analysis was performed with TAGUCHI method and compared the results obtained by S/N Ratio with Analysis of Variance(ANOVA). The results obtained were compared. It is observed that by increase in Nozzle diameter the MRR increases, similarly decrease in Stand-off distance will reduce the divergence of the hole produced.

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